Design of a Periodic Iris-loaded Filter for AccurateTemperatureMeasurementin a Microwave Digestion System

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Introduction

Laboratory microwave digestion systems are used in analytical chemistry to expedite sample preparation for atomic spectroscopy. NOVA*WAVE* is a new automated digestion system that is unlike other oven-type systems in that it is designed around a digestion tunnel. It permits a progressive feed of sample digestion racks with complimenting geometry to form 12 dynamic microwave minicavities in the tunnel. When positioned, simultaneous digestion of up to 12 samples in quartz or Teflon vessels is possible. This permits flexible definition and execution, where each sample is processed *via* individualized methods defined for particular channels. Furthermore, this fully automated system, shown in Figure 1, performs unattended digestion, cooling, and depressurization of up to 168 samples.

One of the key features of the system is the real-time vessel temperature tracking of all channels. This permits control of the radio-frequency (RF) power delivered to the individual sample vessels to ensure execution of a pre-defined temperature trajectory for chemical decomposition. The system operates a closed-loop, where the measured temperature is the feedback to the RF power regulator; the amplitude of the RF signal is correlated directly to the slope of the temperature rise.

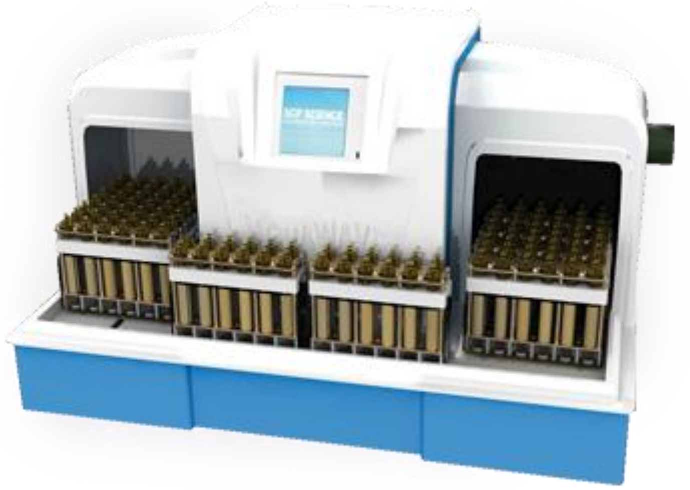

Figure 1: The NOVA*WAVE* fully automated microwave digestion system.

The NOVA*WAVE* utilizes infrared (IR) thermometers (or sensors) to determine vessel temperature. Heat emitted as IR from a vessel surface is detected by its associated sensor and the subsequent electrical signal is converted to the vessel temperature, which is then used as the control feedback for input RF power. To avoid any impact from an elevated ambient temperature during microwave digestion, the sensors are located outside of the system enclosure. Sensors receive the IR radiation from the bottom surface of individual vessels *via* corresponding holes in the tunnel floor. However, the holes introduce three drawbacks:

1. Loss of microwave power.
2. Microwave interference of thermopiles and resultant inaccurate temperature readings.
3. RF emission and compromise of the system electromagnetic compatibility.

To address these issues, a frequency selective structure was designed that is transparent to IR while filtering the RF wave in 2.45GHz. The design basis of this frequency selective structure relies on a periodic structure which is described in the following section.

The Iris Loaded Periodic Structure

Periodic structures are widely used in RF and microwave engineering because of their ability to create passbands and stopbands. The passband is a range of frequencies over which the structure allows electromagnetic waves to propagate. On the other hand, the stopband is a range of frequencies over which the structure blocks electromagnetic waves.

To solve the problems mentioned in the previous section, a periodic structure was proposed in which the 2.45 GHz frequency falls into the stopband while a representative IR frequency of 300 GHz falls into the passband.

The designed periodic structure is illustrated in Figure 2. For each vessel location in the tunnel, this cylinder shaped structure is installed in the thermopile holes between the bottom of the vessels containing the samples and the thermopile lenses. The outer diameter of the cylinder is 1.8 cm while the inner diameter of each iris is 0.85 cm.

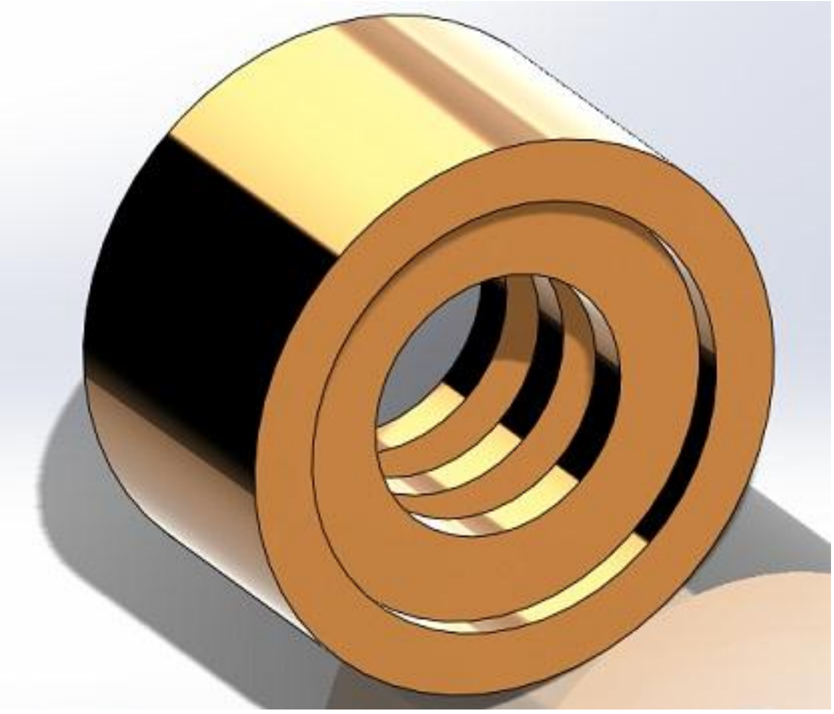

Figure 2: Iris-loaded periodic structure.

Finite Element Analysis

The periodic structure described in the previous sections was analyzed using the full wave 3D high frequency finite element simulation software, HFWorks. The structure was discretized into a finite element mesh and the analysis was conducted with the S-parameter solver. The meshed structure, shown in Figure 3, is the complement (or air-filled negative) of the periodic structure. This approach to the simulation model is based upon analysis is in the Gigahertz frequency range and the skin effect depth of aluminum in the range of micron-level. Therefore, a perfect electric conductor boundary condition is applied, and meshing of the metallic part is avoided.

For the frequency sweep, the fast sweep option was used, where one frequency point was defined as an expansion point. A full size matrix was solved for the expansion frequency, while for the other frequency points, only solution of a reduced order model was required. As the focus of these analyses was the single 2.45 GHz frequency and preferably a limited band, the fast sweep was an efficient option to expedite the simulation.

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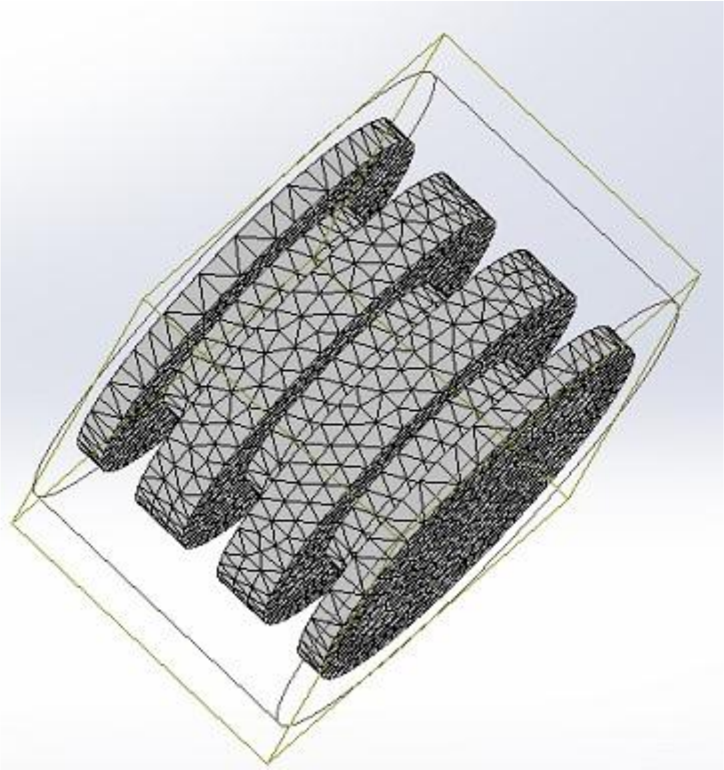

Figure 3: Meshed model of the periodic structure geometry compliment.

Figure 4 shows the electric field distribution in the periodic structure for 2.45GHz. As illustrated, since the 2.45 GHz frequency is in the stopband of this periodic structure, the field cannot go through the cylinder and is stopped. Consequently, the power is reflected back into the tunnel.

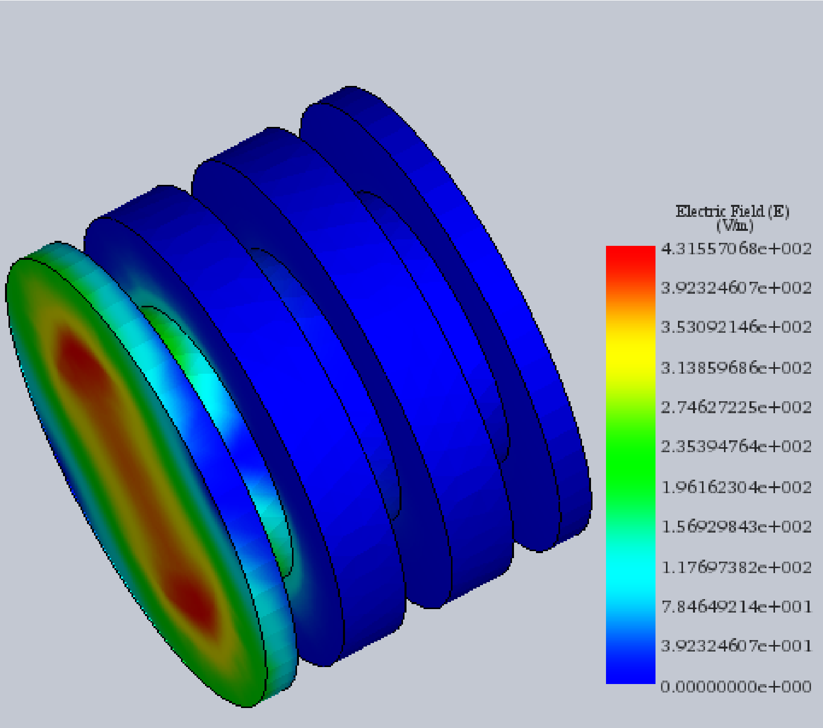

Figure 4: The electric field distribution in the periodic structure for 2.45GHz.

Figure 5 shows the electric field distribution for the same structure but for the 300 GHz frequency. As this result shows, the field can easily pass through the cylinder as this frequency is in the passband of the structure.

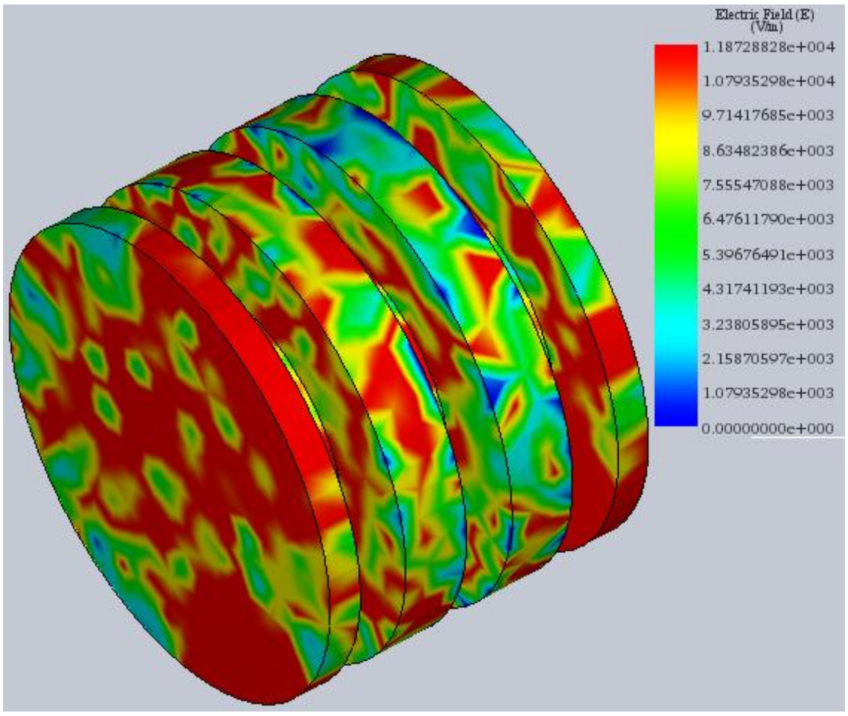

Figure 5: The electric field distribution in the periodic structure for 300 GHz

In addition to simulation of the structure with HFWorks, a sample was fabricated out of aluminum and tested at SCP SCIENCE. Simulation results were confirmed with practical instrument test results. Simulation expedited development testing to a successful design implementation.

In conclusion, we have developed a structure which does not allow the microwave pass, but permits the IR pass freely. Therefore we are able to measure the digestion vessel temperatures without compromising the accuracy. Meanwhile the EMI regulations are respected.